9

Generating and Testing Hypotheses

Tisha, a 2nd grader, stared up at the sky for a long time and then announced, "I think we are going to have a bad storm. It was hot, but now feel how cold it is and look at those cumulus clouds." Her grandma stared in amazement. "Aren't you the weather girl today! Where did you learn all that?" Tisha explained that her teacher had been discussing weather with them all year.

"Our teacher said that weather was there for us to study all year, so why study it all at once and then probably forget it? She said we weren't just going to learn it, we were going to use what we learned. Besides, it means we get to go outside to learn."

Tisha's teacher periodically taught her students about specific weather patterns. Approximately once every two weeks, the class would look at a weather map on the Internet, discuss what had been happening during the last 24 hours, then go outside and observe the sky, once in the morning and once in the afternoon. The students would then predict what they thought would happen between the end of the school day and the next morning. They would also explain the reasoning behind their predictions.

During the first few minutes of the following morning, students discussed their hypotheses and the extent to which they were correct. If their predictions were accurate, they identified the observations that helped them the most. If their predictions were inaccurate, students tried to figure out what they missed or misunderstood.

Tisha's teacher has used the topic of weather to engage students in one of the most powerful and analytic of cognitive operations—generating and testing hypotheses.

Research and Theory on Generating and Testing Hypotheses

By definition, the process of generating and testing hypotheses involves the application of knowledge. It is something we do quite naturally in many situations (see Hansell, 1988; Heller & Reif, 1984; Koedinger & Anderson, 1993; Koedinger & Tabachneck, 1994). For example, a student is involved in generating and testing hypotheses if, after watching a demonstration of how air flow travels over the wing of an airplane, he concludes that changing the shape of the wing in a specific way will have a specific effect on the flow of air. The student would then actually design a wing with the desired shape and then test his conjecture. Figure 9.1 summarizes some of the research on this general category of instructional strategy.

Two generalizations can guide the use of hypothesis generation and testing in the classroom.

1. **Hypothesis generation and testing can be approached in a more inductive or deductive manner.** Deductive thinking is the process of using a general rule to make a prediction about a future action or event (see Johnson-Laird, 1983). For example, while beginning to read a story about a particular wolf, you will naturally access some of the generalizations you have about wolves from your permanent memory. If one of those generalizations is "Wolves run in packs and are highly social," then you will predict that the story will contain episodes about the interaction of the individual wolf with other wolves that are members of a pack.

Inductive thinking, on the other hand, is the process of drawing new conclusions based on information we know or are

FIGURE 9.1

Research Results for Generating and Testing Hypotheses

Synthesis Study	Focus	No. of Effect Sizes (ESs)	Ave. ES	Percentile Gain
Hattie et al., 1996	General effects of generating and testing hypotheses	2	.79	28
Lott, 1983	General effects of generating and testing hypotheses	22	.04	2
Ross, 1988	General effects of generating and testing hypotheses	104	.72	26

presented with (see Holland, Holyoak, Nisbett, & Thagard, 1986). For example, if you are reading an account of how a particular bear behaved when being observed by a scientist, you would induce that the behaviors the scientist had frequently observed are behaviors the bear habitually engages in, or even behaviors that all bears habitually engage in. It is worth noting that thinking in real life is probably never purely inductive or deductive. Rather, scholars assert that reasoning is often more "messy" and nonlinear than earlier definitions suggest (Deely, 1982; Eco, 1976, 1979, 1984; Medawar, 1967; Percy, 1975).

Inductive instructional techniques require students to first discover the principles from which hypotheses are generated. In the air flow example, a teacher would be using an inductive approach if she asked students first to discover principles about air flow and then to generate hypotheses based on these discovered principles. A teacher would be using a deductive approach, however, if she first presented students with principles of air flow, such as the Bernoulli theorem. With this knowledge as a basis, she would then ask students to generate and test hypotheses based on the principles they have been taught. Although both inductive and deductive approaches can work well, generally speaking, deductive approaches produce better results. To illustrate, consider the research findings in Figure 9.2.

As reported in the last two rows of Figure 9.2, the average effect size for deductive techniques is much larger than that for inductive techniques (.60 versus .39). This is not to say that inductive approaches cannot produce large effect sizes. Perhaps teachers find inductive approaches more difficult to execute correctly. Inductive strategies require a well-orchestrated set of experiences so that students might infer accurate and appropriate principles from which to generate hypotheses. In the absence of experiences that allow students to do this, it is probably better to present principles directly to students and then ask them to generate hypotheses.

2. Teachers should ask students to clearly explain their hypotheses and their conclusions. A fair amount of research has demonstrated the power of asking students to carefully explain—preferably in writing—the principles they are working from, the hypotheses they generate from these principles, and why their hypotheses make sense (see Lavoie, 1999; Lavoie & Good, 1988; Lawson, 1988). Apparently, the process of explaining their thinking helps students deepen their understanding of the principles they are applying. If an inductive approach is being used, students might be asked to explain the logic underlying their observations, how their observations support their hypotheses, how their experiment tests their hypotheses, and how their results confirm or disconfirm their hypotheses. If a deductive technique is being

FIGURE 9.2

Inductive versus Deductive Approaches

Synthesis Study	Focus	No. of Effect Sizes (ESs)	Ave. ES	Percentile Gain
Tamir, 1985	Deductive techniques	13	.27	11
Lott, 1983	Deductive techniques	18	.02	1
	Inductive techniques	4	.10	4
El-Nemr, 1980	Inductive techniques	250	.38	15
Sweitzer & Anderson, 1983	Inductive techniques	19	.43	17
Walberg, 1999	Inductive techniques	38	.41	16
Ross, 1988	Inductive techniques	39	.48	19
	Deductive techniques	65	.83	30
Average ES for inductive techniques		380	.39	15
Average ES for deductive techniques		96	.60	23

used, students would not be engaged in the observation phase of this process.

Classroom Practice in Generating and Testing Hypotheses

Using a Variety of Structured Tasks to Guide Students Through Generating and Testing Hypotheses

Although the process of generating and testing hypotheses is commonly associated with the scientific method, teachers can use the process in different tasks across all disciplines. The following six types of tasks all employ hypotheses generation and testing.

Systems Analysis. Students at all grade levels study many systems across the disciplines, such as ecosystems, anatomical systems, systems of government, and transportation systems. One way to enhance and use students' understanding of these systems is to ask them to generate hypotheses that predict what would happen if some aspect of a system were changed. The following general framework for systems analysis might be useful in guiding students' work.

1. Explain the purpose of the system, the parts of the system, and the function of each part.

2. Describe how the parts affect each other.

3. Identify a part of the system, describe a change in that part, and then hypothesize what would happen as a result of this change.

4. When possible, test your hypothesis by actually changing the part or by using a simulation to change the part.

Problem Solving. By definition, problems involve obstacles and constraints. While engaged in solving problems, students must generate and test hypotheses related to the various solutions they predict might work. For example, a teacher might present students with a task that requires them to build something (e.g., a model car, a bridge) under the constraint that they are allowed to use limited or specific materials only (e.g., balsa wood, a rubber band, a mousetrap). Using their understanding of concepts related to the problem (e.g., inertia, gravity, energy, force, and motion) they must consider different approaches to a solution and then generate and test their hypotheses about those solutions. Students might use the following general framework to guide their work.

1. Identify the goal you are trying to accomplish.

2. Describe the barriers or constraints that are preventing you from achieving your goal—that are creating the problem.

3. Identify different solutions for overcoming the barriers or constraints and hypothesize which solution is likely to work.

4. Try your solution—either in reality or through a simulation.

5. Explain whether your hypothesis was correct. Determine if you want to test another hypothesis using a different solution.

Historical Investigation. Students are engaged in historical investigation when they construct plausible scenarios for events from the past, about which there is no general agreement. For example, scholars have presented conflicting versions of Roosevelt's role in the events that led up to the bombing of Pearl Harbor. To engage in historical investigation, students need to use their understanding of the situation to generate a hypothetical scenario. To test this hypothesis, each student must then seek out and analyze as much information as possible to determine if the hypothesis is supported by the evidence. Students might use the following general framework for historical investigation:

1. Clearly describe the historical event to be examined.

2. Identify what is known or agreed on and what is not known or about which there is disagreement.

3. Based on what you understand about the situation, offer a hypothetical scenario.

4. Seek out and analyze evidence to determine if your hypothetical scenario is plausible.

Invention. Another task that requires students to generate and test hypotheses is the process of invention. For example, students might use their understanding of the principles of the cardiovascular and muscular system to invent a new form of exercise. To do this, they must hypothesize what might work, develop the idea, and then conduct tests to determine if their idea does, in fact, work. Invention often demands generating and testing multiple hypotheses, until one of them proves effective. As students engage in invention, they might use the following general framework as a guide:

1. Describe a situation you want to improve or a need to which you want to respond.
2. Identify specific standards for the invention that would improve the situation or would meet the need.
3. Brainstorm ideas and hypothesize the likelihood that they will work.
4. When your hypothesis suggests that a specific idea might work, begin to draft, sketch, or actually create the invention.
5. Develop your invention to the point where you can test your hypothesis.
6. If necessary, revise your invention until it reaches the standards you have set.

Experimental Inquiry. We most commonly associate the process of experimental inquiry with generating and testing hypotheses in science. But teachers can use experimental inquiry across the disciplines to guide students in applying their understanding of important content. For example, based on their understanding of how literary devices in literature have influenced readers, students might hypothesize the effects of using specific literary devices in their own writing. Teachers might use the following general framework to help students engage in any experimental inquiry task:

1. Observe something of interest to you and describe what you observe.
2. Apply specific theories or rules to explain what you have observed.
3. Based on your explanation, generate a hypothesis to predict what would happen if you applied the theories or rules to what you observed or to a situation related to what you observed.
4. Set up an experiment or engage in an activity to test your hypothesis.
5. Explain the results of your experiment or activity. Decide if your hypothesis was correct and if you need to conduct additional experiments or activities or if you need to generate and test an alternative hypothesis.

Decision Making. Although we might not associate decision with generating and

testing hypotheses, using a structured decision-making framework can help students examine hypothetical situations, especially those requiring them to select what has the *most* or *least* of something or what is the *best* or *worst* example of something. For example, if students were asked to predict who is the most influential musical group or visual artist of the last decade, many students would quickly offer a prediction. If they were then asked to test this hypothesis by using a structured decision-making framework, the result might be different from what they predicted. Further, using a decision-making process to test their prediction requires them to reflect on and use a broad range of knowledge related to the topic. Students might use the following framework to guide them through such decision making tasks:

1. Describe the decision you are making and the alternatives you are considering.
2. Identify the criteria that will influence the selection and indicate the relative importance of the criteria by assigning an importance score from a designated scale, for example, 1–4.
3. Rate each alternative on a designated scale (e.g., 1–4) to indicate the extent to which each alternative meets each criterion.
4. For each alternative, multiply the importance score and the rating and then add the products to assign a score for the alternative.
5. Examine the scores to determine the alternative with the highest score.
6. Based on your reaction to the selected alternative, determine if you need to change any importance scores or add or drop criteria.

The following example shows how teachers can use more than one of these processes within a single topic.

Mr. Sanders wanted to present his 10th grade students with a variety of ways to test and generate hypotheses in his unit on World War II. After teaching the students some basic facts and issues about the war, he asked them to select one of the following projects:

Decision Making. What is your hypothesis as to the best method of ending World War II other than the use of the atomic bomb? Use the decision-making framework to test your hypothesis.

Problem Solving. If you were president of the United States during World War II, how would you force the unconditional surrender of Japan without using the atomic bomb and yet provide for a secure, post-war world?

Investigation. Why did Japan attack Pearl Harbor? Some say President Roosevelt intentionally provoked the Japanese. Others disagree. What is your hypothesis? Collect evidence that confirms this hypothesis.

Making Sure Students Can Explain Their Hypotheses and Their Conclusions

The second generalization in this category of instructional strategies reminds us

to ask students to explain their thinking as they generate and test hypotheses. Teachers can design assignments so that students know they must be able to describe how they generated their hypotheses and to explain what they learned as a result of testing them. For example, a teacher might

- Provide students with templates for reporting their work, highlighting the areas in which they will be expected to provide explanations.
- Provide sentence stems for students, especially for young students, to help them articulate their explanations.
- Ask students to turn in audiotapes on which they explain their hypotheses and conclusions.
- Provide, or develop with students, rubrics so that they know that the criteria on which they will be evaluated are based on the quality of their explanations.
- Set up events during which parents or community members ask students to explain their thinking.

The following example shows how an art teacher might design assignments that require students to explain how they generated and tested hypotheses.

The 5th grade art teacher had finally found a way for students to demonstrate and enhance their understanding of how the elements of a painting work together as a system (e.g., color influences the impact of perspective and is influenced by texture, etc.). Through a projection system connected to her computer, she projected a famous painting on the screen in front of the classroom. She then told the students that she could change a single element (color, depth, contrast) with the computer. Before she changed each element, the students, working in pairs, were asked to predict how they thought changing one element would influence the impact of the other elements. She then made the suggested change and allowed students time to react. After each change, she selected students to explain to the class what they predicted the effect would be, why their prediction was logical, and the extent to which their prediction was confirmed or disconfirmed.

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We commonly think of generating and testing hypotheses as the purview of the science teacher only. As this chapter has shown, this basic cognitive skill applies to a variety of tasks that are applicable to many subject areas.